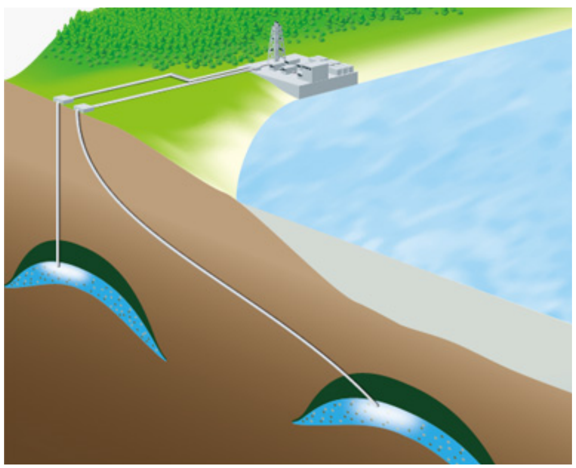
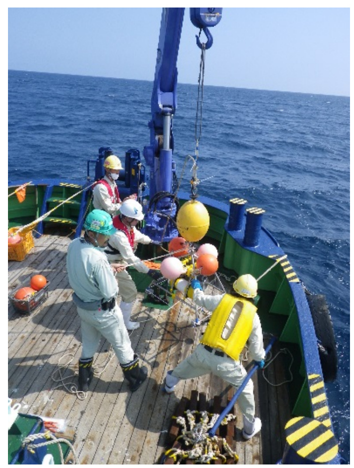
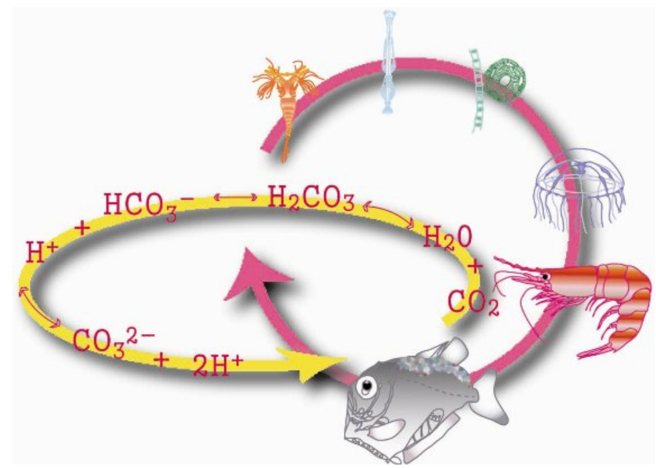
19-21 April 2016, Gulf Coast Carbon Centre, University of Texas, Austin, Texas.

International Workshop on Offshore Geologic CO_2 Storage

How to do environmental monitoring offshore, Japan case study





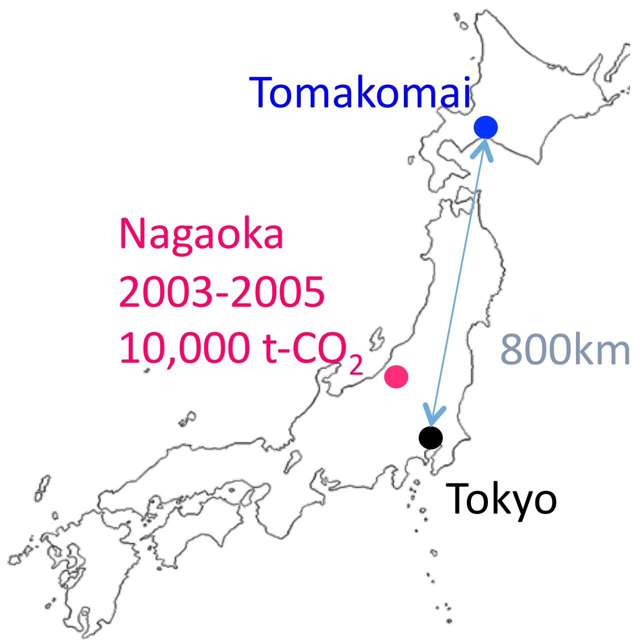


Jun Kita

Research Institute of Innovative Technology for the Earth

Marine Ecology Research Institute

Tomakomai CCS Demonstration Project



- Ministry of Economy, Trade and Industry (METI)
- Japan CCS Co., Ltd. http://www.japanccs.com
- 100,000 tonnes/year or more CO_2 is to be stored under the seabed.
- CO_2 injection will start in 2016 and continued to 2018.

Off-gas supply:
hydrogen production facility at oil refinery plant

↓

CO_2 capture:
amine absorption

→

CO_2 injection:
onshore

↓

Reservoirs:
under the seabed

- Sandstone layer: 1100-1200m depth
- Volcanic rocks layer: 2400-3000m depth

Offshore CO_2 storage and London Protocol

London Protocol

- London Convention: An agreement to control pollution of the sea by dumping.
- 1996 Protocol: The Parties are obligated to prohibit the dumping of any waste or other matter that is not listed in Annex 1 (the reverse list).
- Adopted on 2006: Carbon dioxide streams may only be considered for dumping, if disposal is into a sub-seabed geological Formation”

Act for the Prevention of Marine Pollution and Maritime Disasters

- May 2007: The act was amended for permit procedure on dumping CO_2 stream into sub-seabed formation.
- Prevention of marine environment impact from potential CO_2 leakage

Operator of Offshore CO_2 storage,

- Shall receive permission from environment minister.
- Shall implement Environmental Impact Assessment.
- Shall monitor surrounding sea environment.

Environmental Impact Assessment (EIA) in the ACT

Objective

- Estimation of CO_2 dispersion and its impact assessment on the assumption that stored CO_2 leaks out to the sea

Process

- Consideration of leakage scenarios and its simulation
  - CO_2 migration in the geological formation
  - CO_2 dispersion in the seawater column
- Base-line survey for the existing marine environment
- Impact assessment

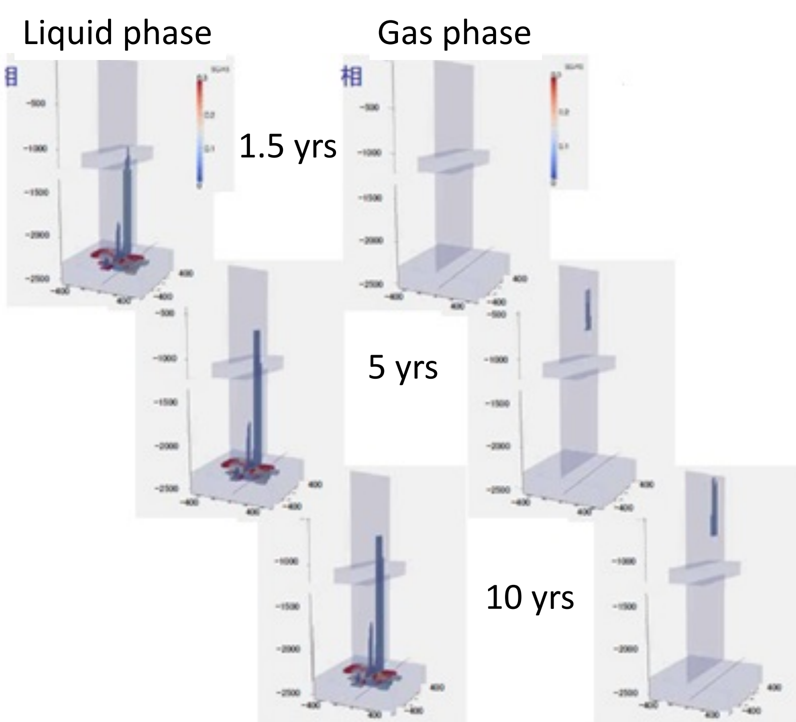
Example of leakage simulations

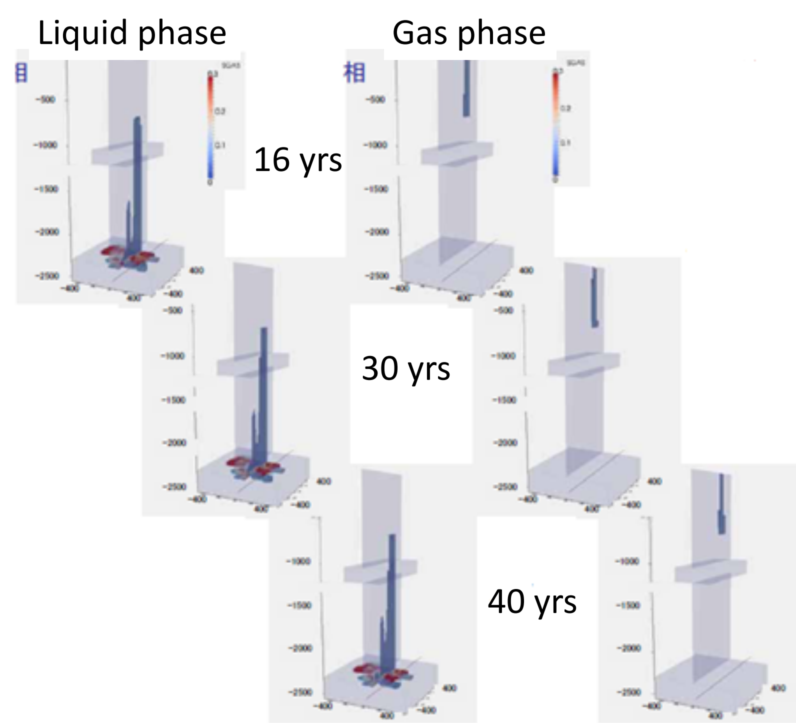
CO_2 migration in the geological formation

Scenario: Leakage through faults undetectable by seismic survey

Simulator: TOUGH2 with ECO2M (LBNL)

Output: CO_2 flux at the seafloor





Example of leakage simulations

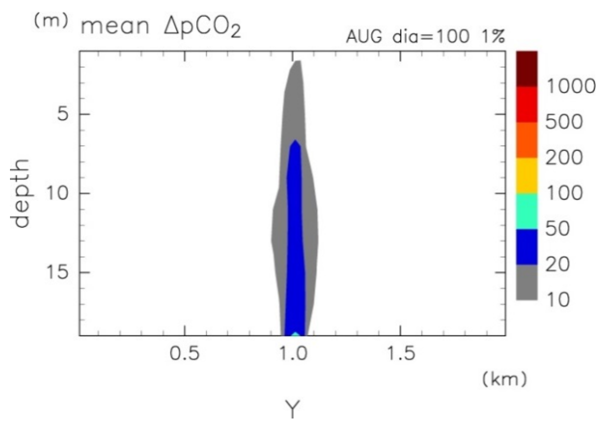
CO_2 dispersion in the seawater

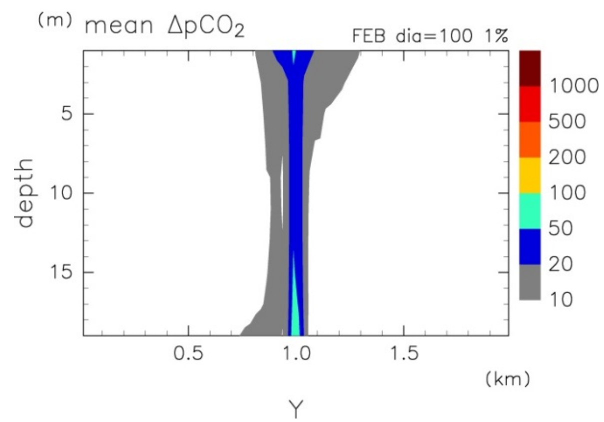
Input: CO_2 flux at the seafloor

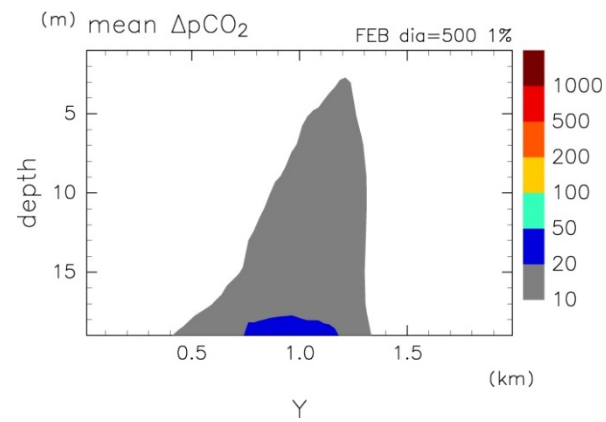
Simulator: MEC-CO2 two-phase flow model

Kano et al., 2010. Model prediction on the rise of pCO_2 in uniform flows by leakage of CO_2 purposefully stored under the seabed. International J. Greenhouse Gas Control 3, 617-625.

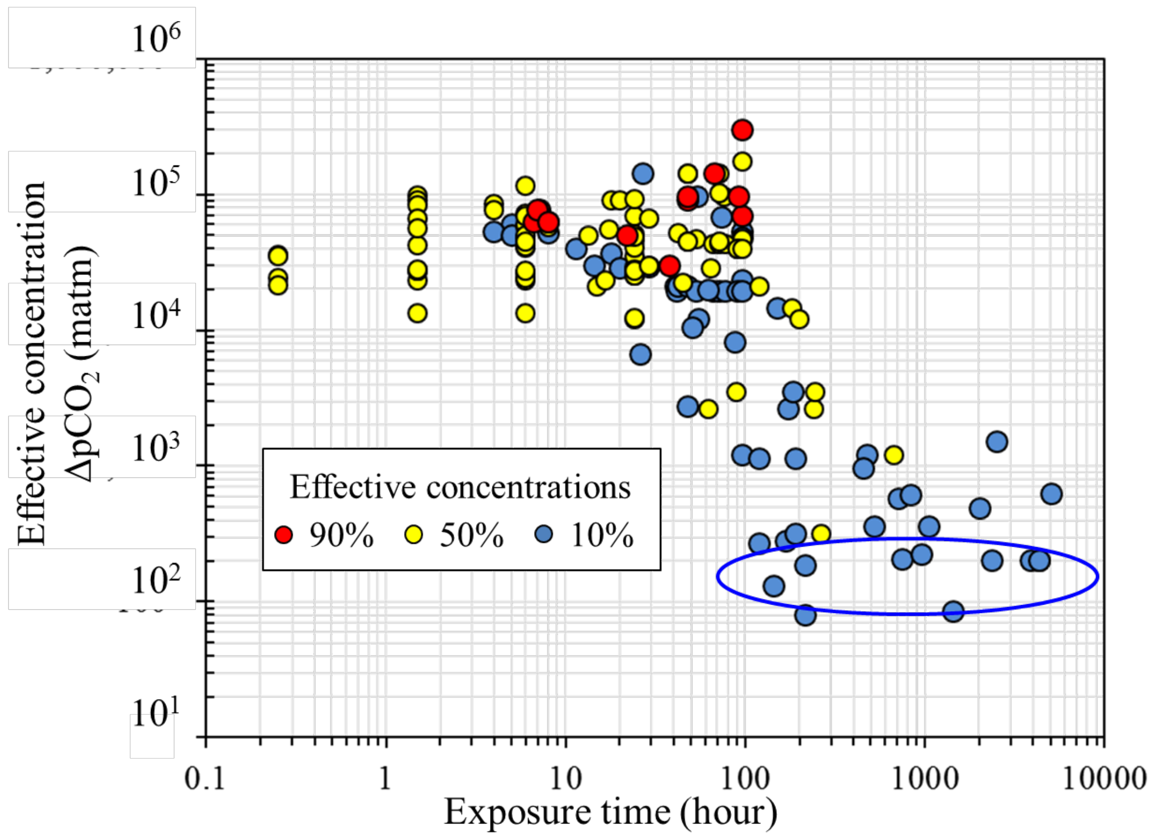
Output: CO_2 concentration gradient in the seawater column







Example of determination of threshold for ecological impact



Ecological CO_2 impact estimated from a biological impact database

CO_2 dispersion in the seawater

Potential impacted area

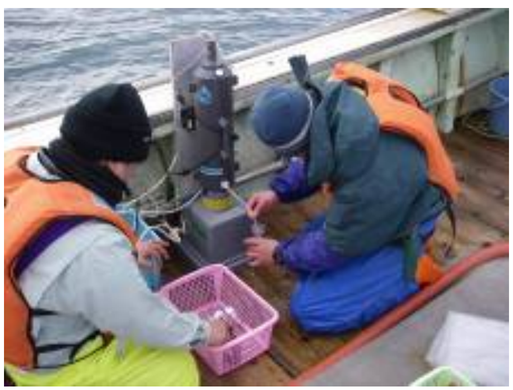
Example of measurements in the base-line survey

Seawater: pH, TCO_2, Alkalinity, DO, etc.

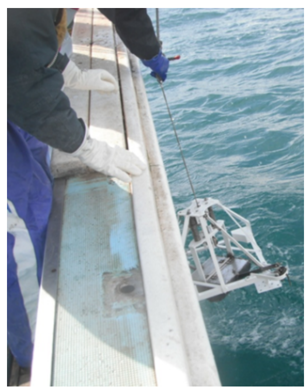
Sediment: pH, pore-water chemistry, etc.

Seabed: side scan sonar, sub-bottom profiler

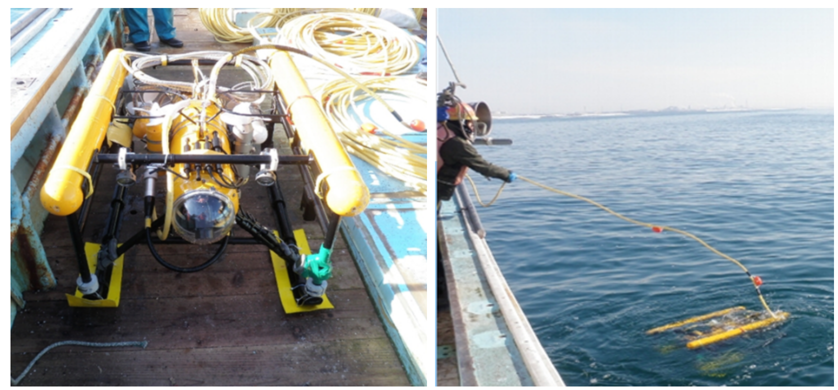
Biology: micro-, meio-, macro-, mega-benthos, etc.



Water sampling



Sediment sampling



ROV for mega-benthos observation

Seawater CO_2 system

As CO_2 dissolves in seawater,

$$CO_2 + H_2O \Leftrightarrow H_2CO_3 \Leftrightarrow HCO_3^- + H^+ \Leftrightarrow CO_3^{2-} + 2H^+$$

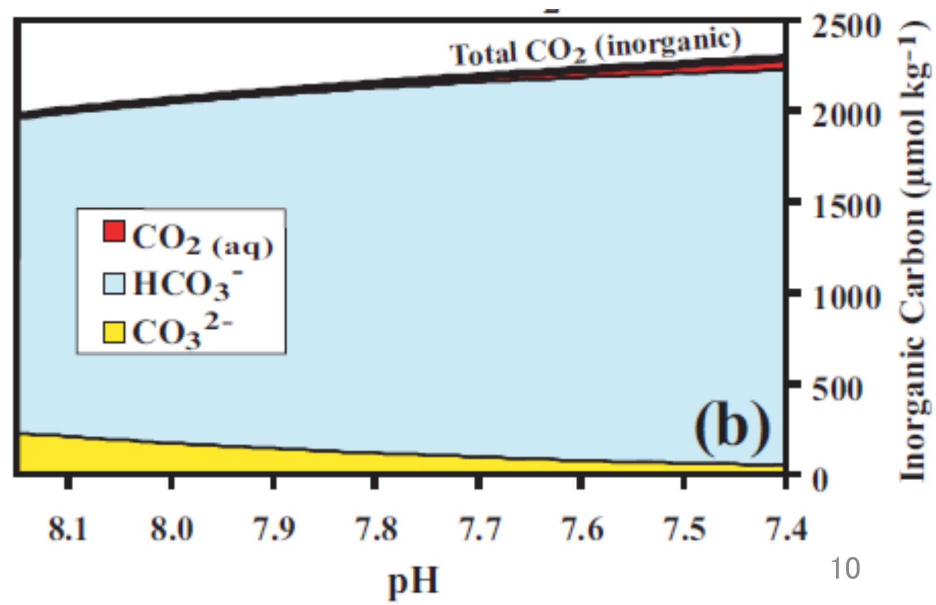
(CO_2aq)

Thus, to increase concentration of

- carbonic acid (H_2CO_3) ⇨ <u>*p*CO_2 increase</u>
- proton (H^+) ⇨ <u>pH decrease, acidification</u>
- bicarbonate ion(HCO_3^-)

while decrease concentration of

- carbonate ion(CO_3^{2-})



Parameters for description of seawater CO_2 system

- **Total dissolved inorganic carbon (DIC)**
- **Total alkalinity (AT)**
- **pH**
- **Partial pressure of CO_2 (pCO_2)**

+

- **Salinity and Temperature**

✓ Dickson, A.G., Sabine, C.L. and Christian, J.R. (Eds.) 2007. **Guide to Best Practices for Ocean CO_2 Measurements**. PICES Special Publication 3, 191 pp

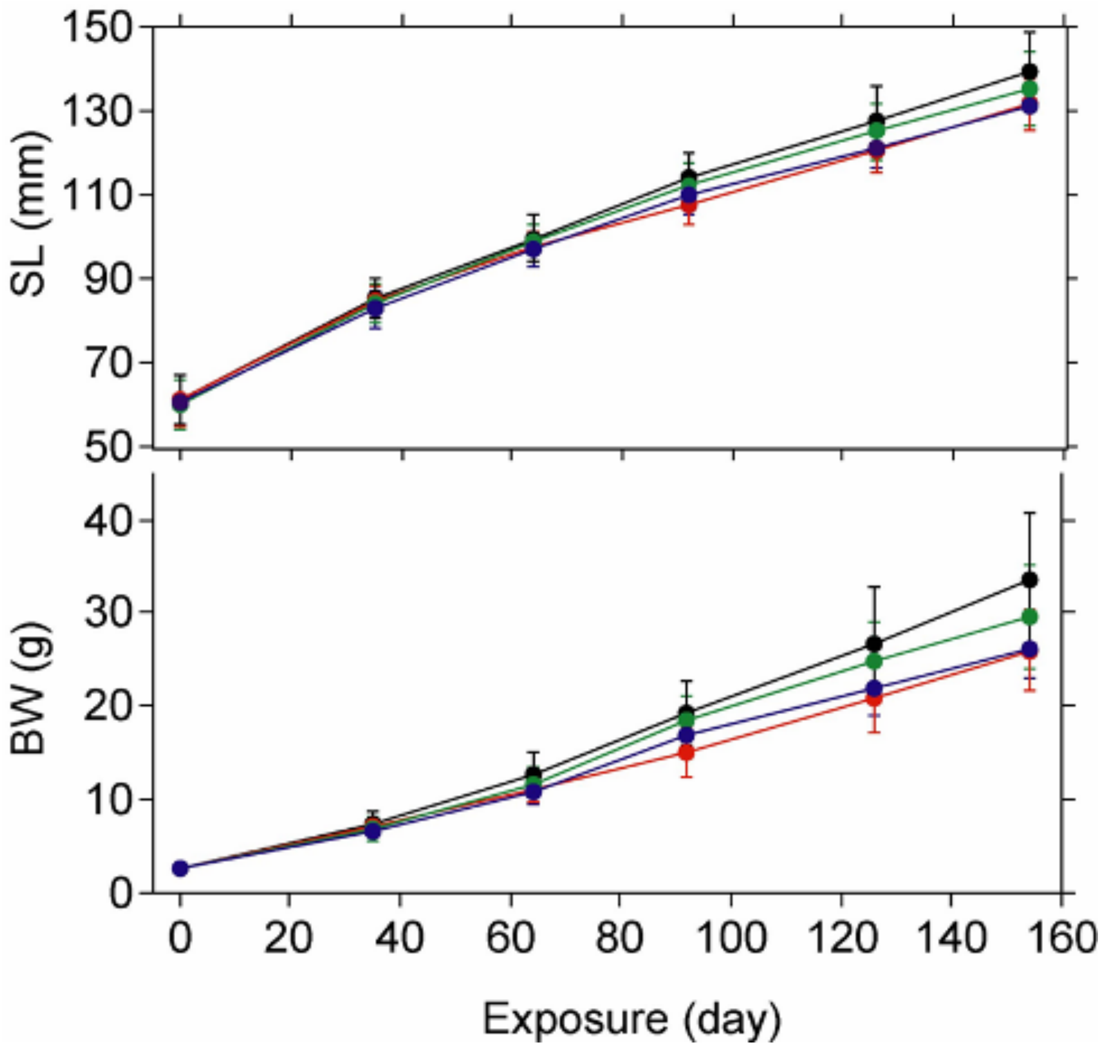
✓ **DIC** and **AT** measurement can be recommended

✓ CO_2 system can be calculated by CO2SYS

http://cdiac.ornl.gov/oceans/co2rprt.html

✓ IEAGHG, 2016. Offshore Monitoring for CCS Projects, Report 2015/02, May 2015

CO_2 Effects on fish growth



Kita et al. unpublished

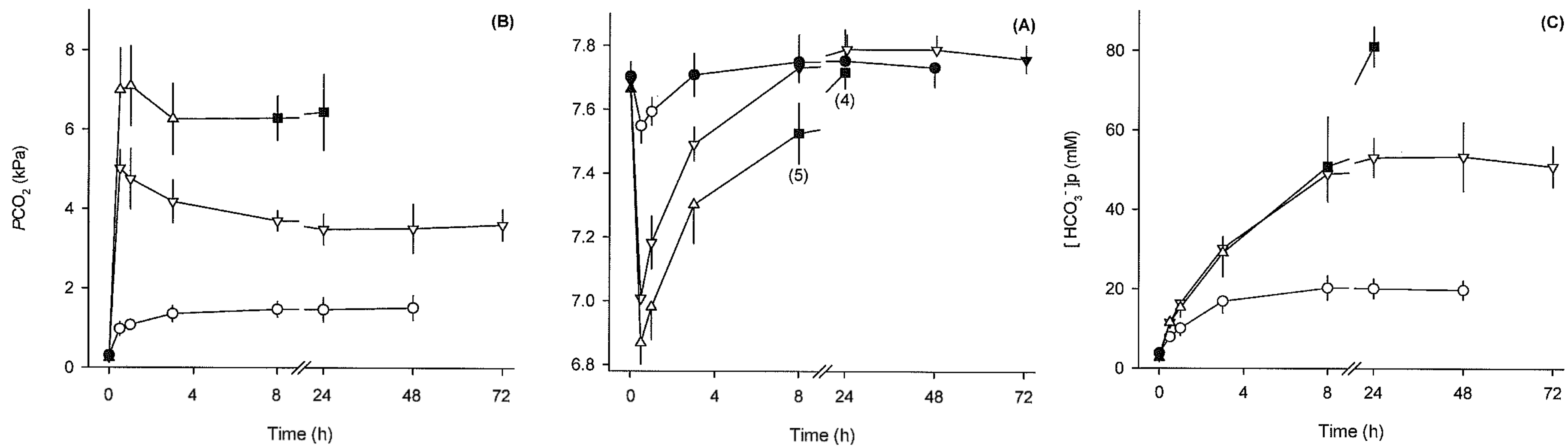
●: pCO_2=400matm (control)
●: pCO_2=4,000matm
●: pCO_2=7,000matm
●: pCO_2=12,000matm
Bars represent SD.

Growth of young *Sillago japonica* under sublethal CO_2 concentration.

CO_2 effects on fish physiology

Hayashi et al. 2004.

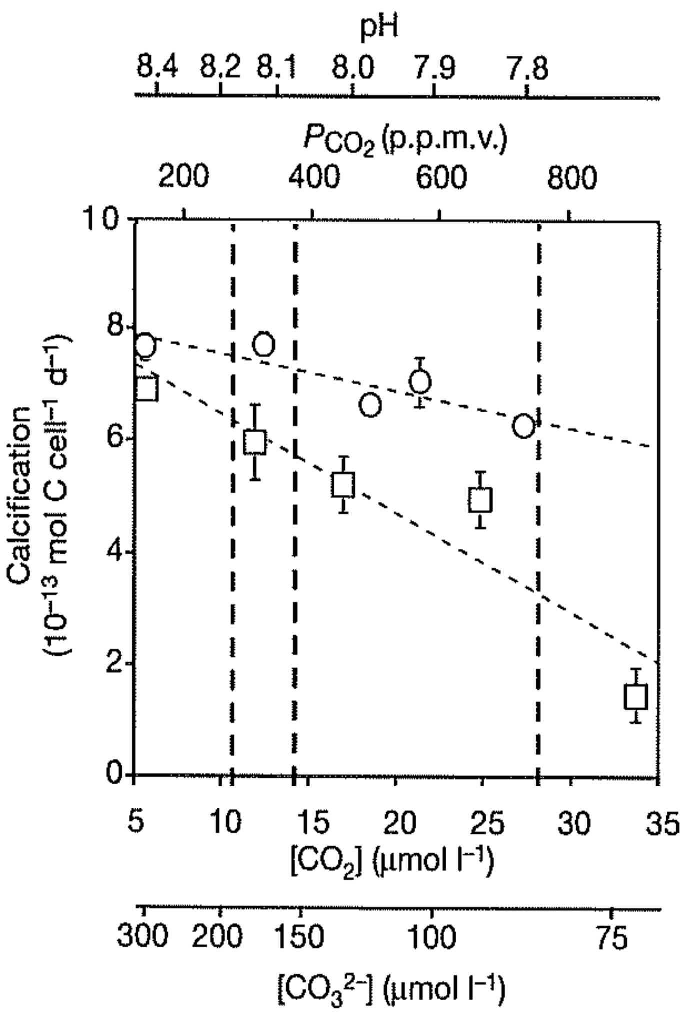
Arterial pCO_2 | Arterial pH | Plasma bicarbonate

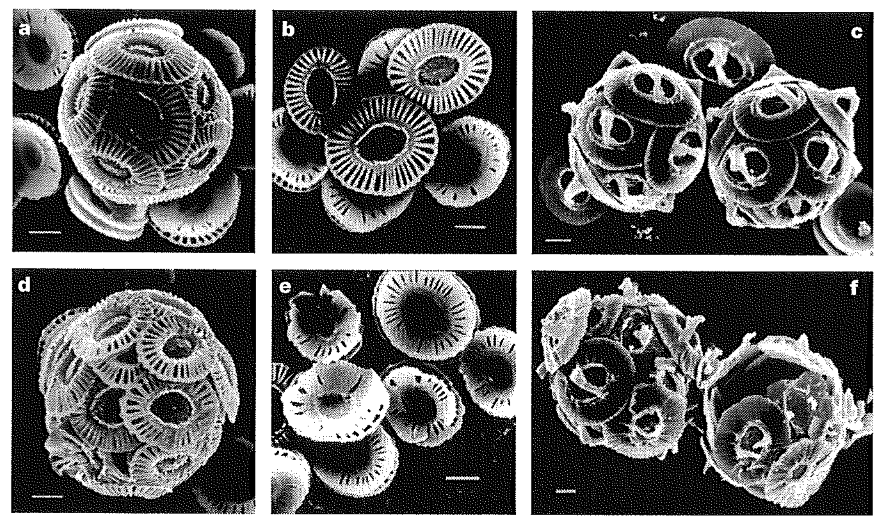


Acid-base change of Japanese flounder during CO_2 exposure of 10,000matm (●), 30,000matm (▼) and 50,000matm (▲).

Effects of high-CO_2 on coccolithophores, phytoplankton with calcite plates

Riebesell et al., 2000





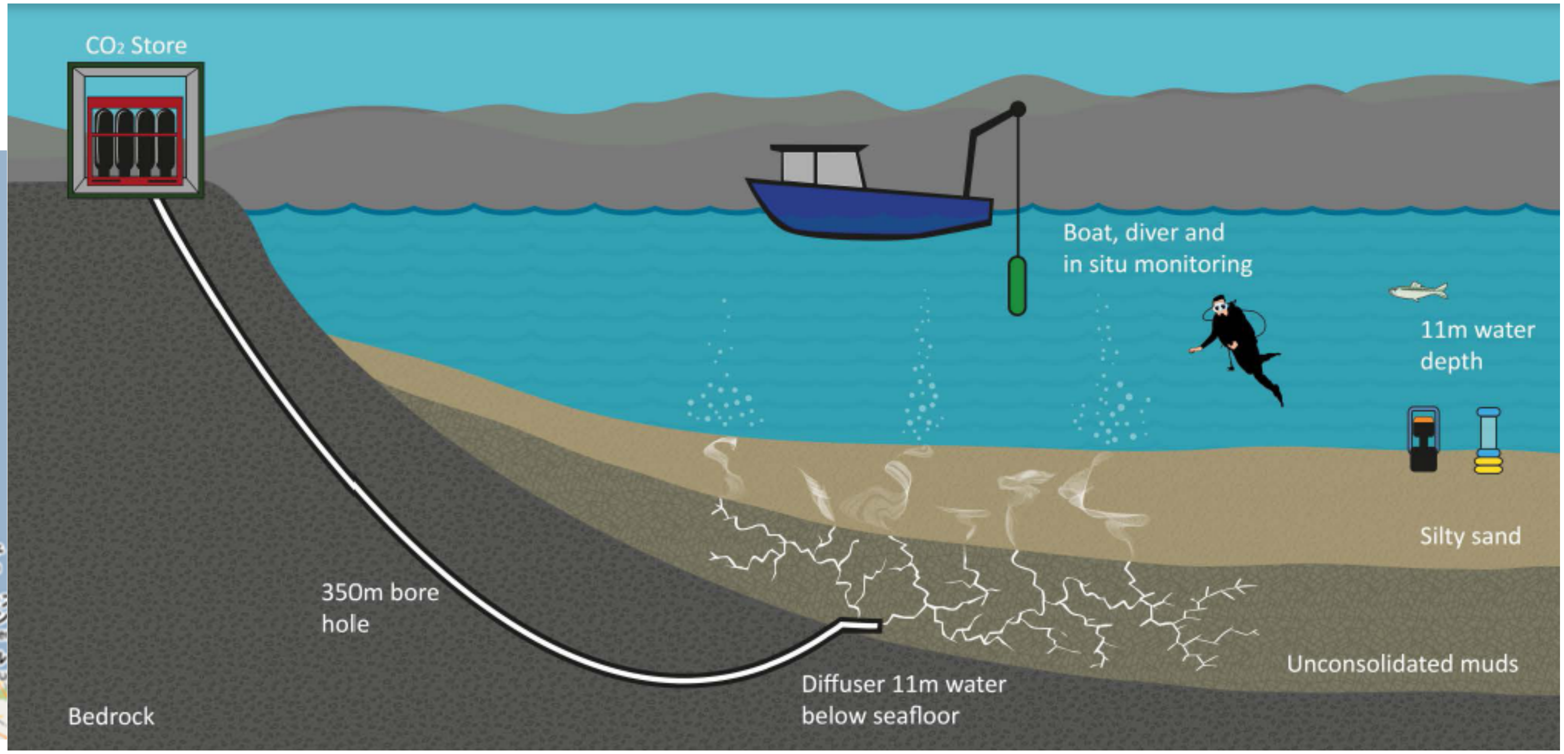
Calcification of the coccolithophorids *Emiliania huxleyi* (○) and *Gephyrocapsa oceanica* (□) as a function of CO_2 concentration.

Effects of high-CO_2 on marine organisms

Organisms	pCO_2	Effect
<u>Calcifiers</u> • Molluscs • Echinoderms • Corals • Coccolithophores	D200µatm <	Calcification decrease
<u>Non-calcifiers</u> • Fish • Molluscs • Copepods	D2,000µatm <	Physiological disturbance

Collaboration with QICS project UK

Quantifying and Monitoring Potential Ecosystem Impacts of Geological Carbon Storage



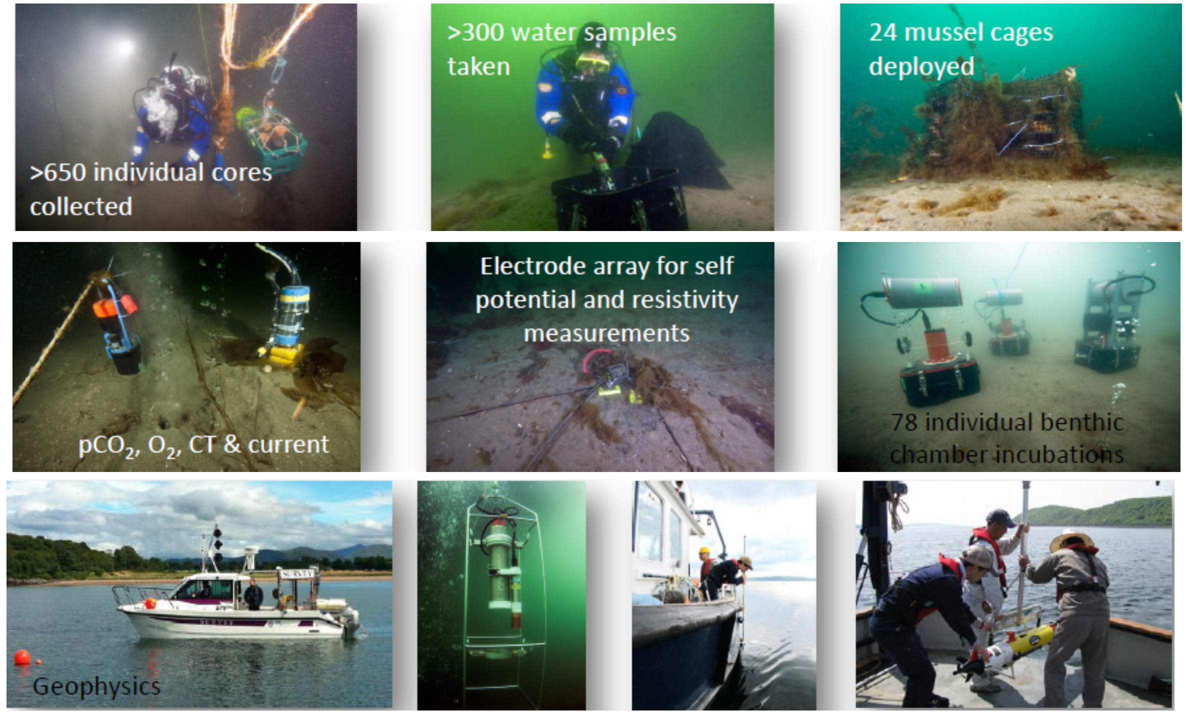
- If CO_2 leaked into the living marine environment what are the likely ecological impacts, would they be significant?
- What are the best tools, techniques and strategies for the detection and monitoring of leaks – or assurance that leakage is not happening, in the vicinity of the sea floor.

Summary from QICS

Diving surveys & sampling

In situ sensors & mesurements

Ship-board mesurements



- The biological impact was minimal and the recovery was rapid.
- Multiple monitoring methodologies in a staged approach are recommended.
- Impacts of CCS leakage should not be seen as an impediment to the development of full scale CCS.

Outputs from QICS

www.qics.co.uk

nature climate change 4, 1011-1016 (2014)

Blackford et al.

Detection and impacts of leakage from sub-seafloor deep geological carbon dioxide storage

INTERNATIONAL JOURNAL OF Greenhouse Gas Control

21 research papers

Special issue: CCS and the Marine Environment

Volume 38, July 2015

Monitoring program required in the ACT

Conformance:

- Observed behavior of CO_2 should fall into line with prediction.

Containment:

- Secure retention of CO_2 should be demonstrated.
  - ✓ Distribution of CO_2 in the reservoir needs to be tracked.
  - ✓ No sign of leakage needs to be shown in marine environment.

Contingency:

- If leakage dose occur,
  - ✓ Amount of leakage needs to be quantified.
  - ✓ Any environmental impacts need to be assessed.

Required monitoring items

CO_2 injection:

- Volume (flow meter), concentration (gas chromatography), injection condition (pressure, rate, temperature)

Wellbore condition:

- Pressure and Temperature of injection well and observation well

Reservoir:

- Location and dimension of stored CO_2 (time-lapse (4D) seismic)

Marine environment:

- Seawater chemistry (pH, TCO_2, Alkalinity, DO, etc.)
- Maine biota (micro-, meio-, macro-, mega-benthos)
- Marine activities (fisheries, maritime affairs, protected reserves, etc.)

Tiered monitoring plan in the Act

Three tiered monitoring plan must be implemented depending on the severity of changes that could occur following CO_2 storage

Routine monitoring:

- No indication of leakage
- Distinguish leakage signal from natural variability

Precautionary monitoring:

- Possible leakage
- Confirm existence or non-existence of leakage

Emergency monitoring:

- Leakage has taken place
- Determine location and extent of the leakage and its impact

Summary - Tomakomai

- The regulation of offshore CO_2 storage in Japan is covered by the Act for the Prevention of Marine Pollution and Maritime Disasters
- The act requires adherence to "conformance", "containment" and "contingency" criteria

Current status:

- Environmental impact assessment — **Completed**
- Permission — **Cleared**
- Monitoring — **Immediately after CO_2 injection**

Concluding Remarks

Environment impact assessment and marine monitoring for offshore CCS:

- ✓ Important for public acceptance
- ✓ Necessitates a wider dialogue between scientists, policymakers, the public and civil society groups
- ✓ International collaboration is highly desirable